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Kane

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[54] **MICROSTRIP CIRCULATOR WITH FERRITE AND RESONATOR IN PRINTED CIRCUIT LAMINATE**

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[73] Assignee: **Motorola, Inc.**, Schaumburg, Ill.

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[51] **Int. Cl.**[4] **H01P 1/387**
[52] **U.S. Cl.** **333/1.1**; 333/238
[58] **Field of Search** 333/1.1, 24.2

[56] **References Cited**

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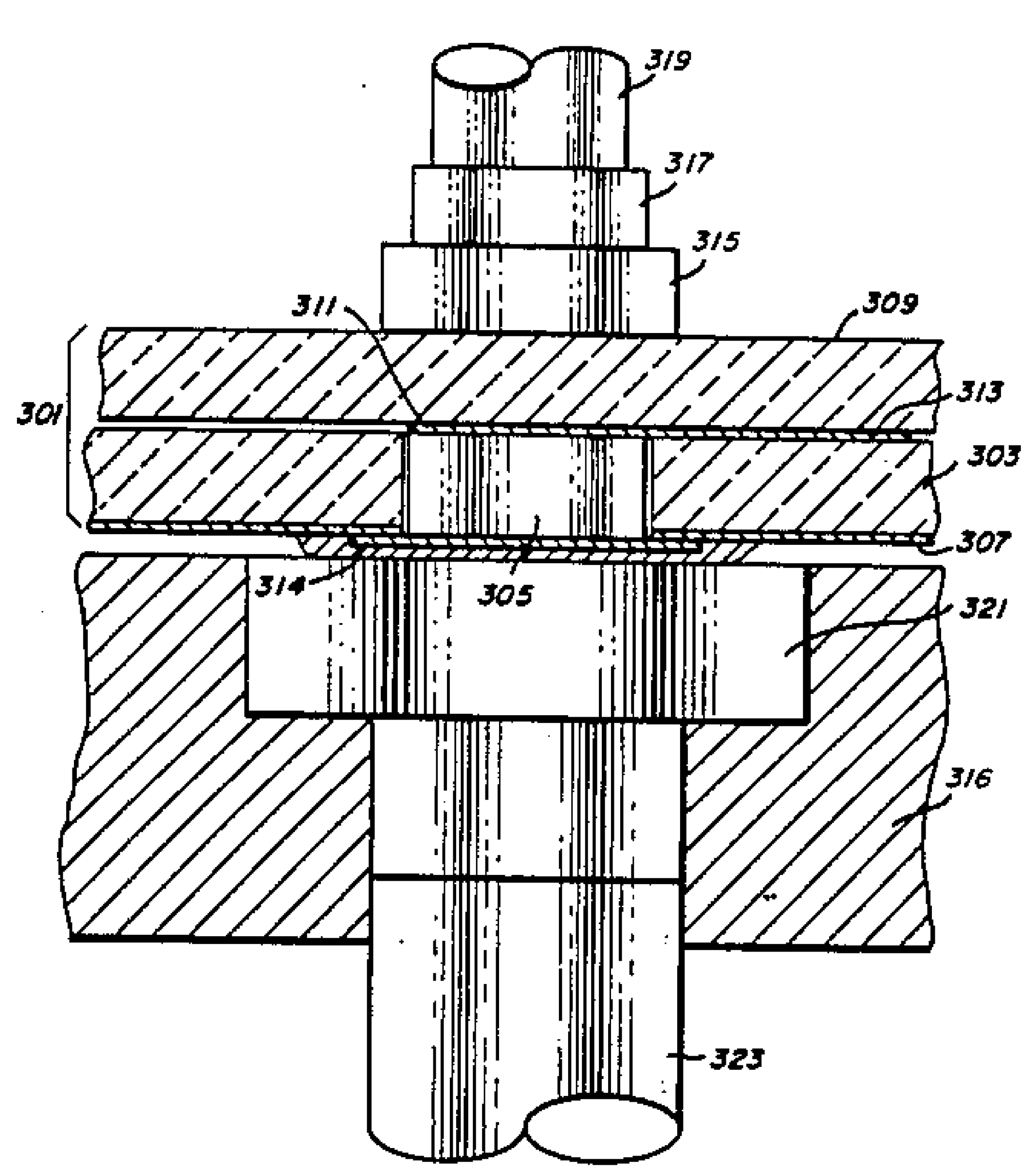
Primary Examiner—Paul Gensler
Attorney, Agent, or Firm—Raymond A. Jenski; Rolland R. Hackbart

[57] **ABSTRACT**

A microstrip circulator is disclosed in which a resonator (**311**) is metalized on one layer (**309**) of a multilayer printed circuit board (**301**) and a ferrite element (**305**) is disposed in another layer (**303**) of the circuit board. Input/output port termination mismatch due to port lead misalignment is eliminated and ferrite to resonator coupling is accomplished in a simple and repeatable manner.

16 Claims, 11 Drawing Figures



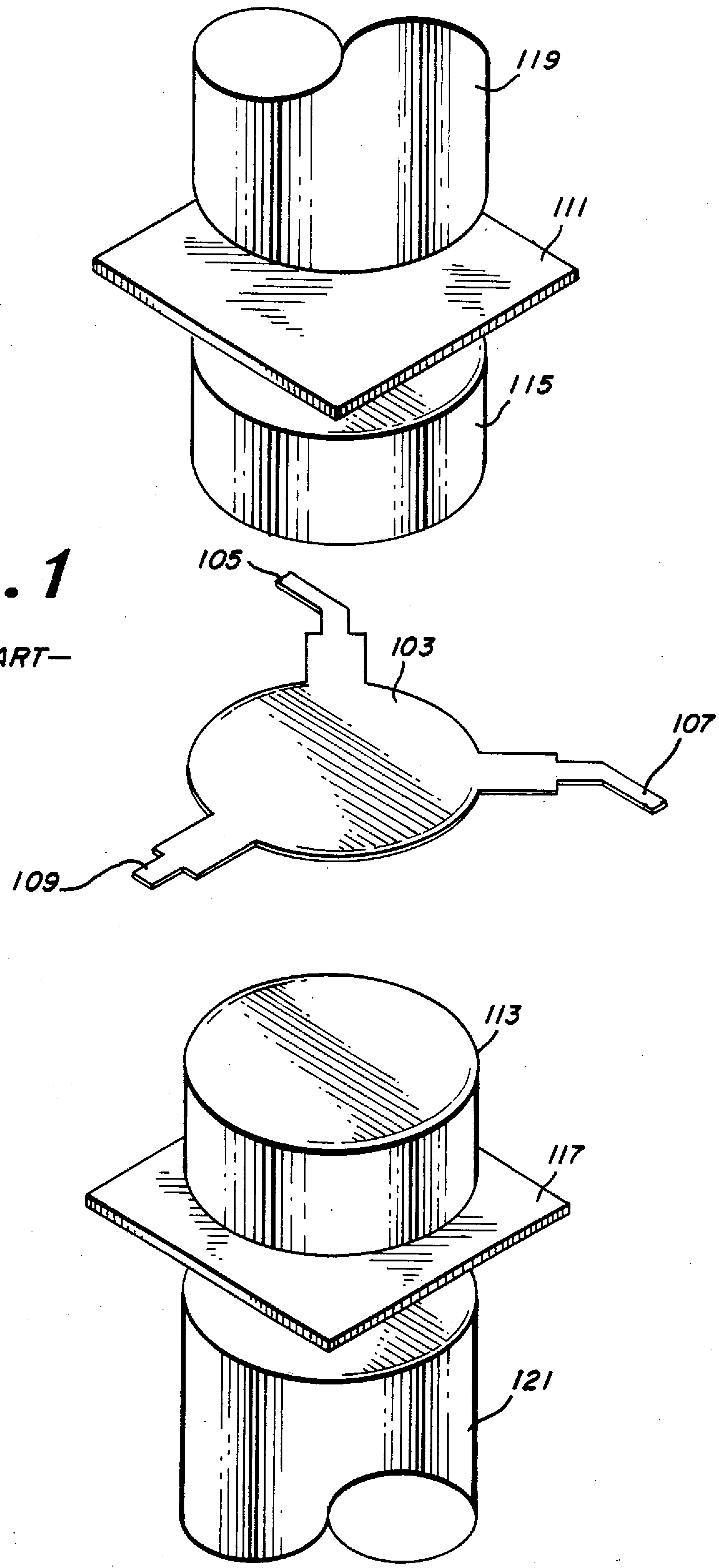


FIG. 1
—PRIOR ART—

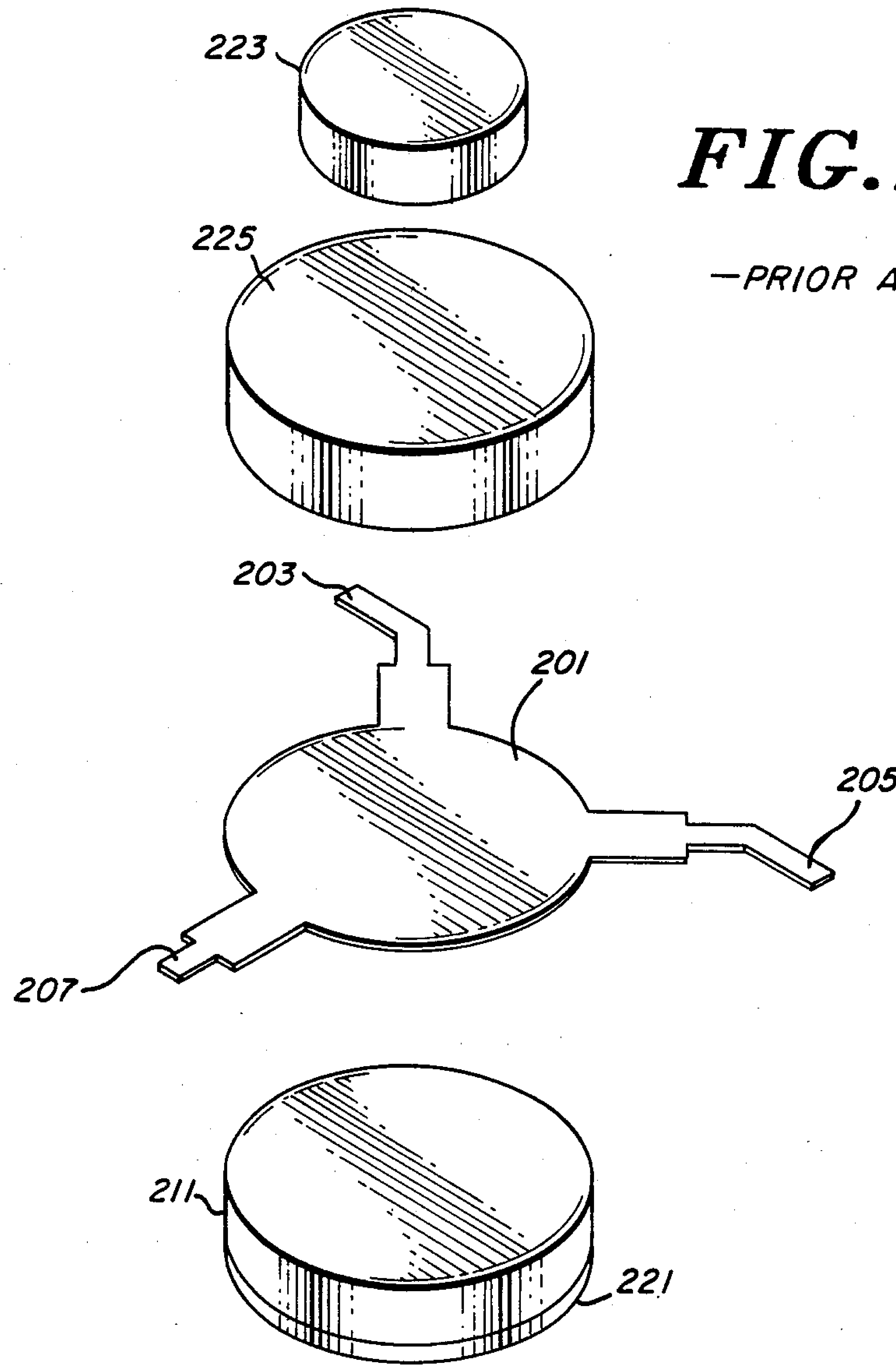
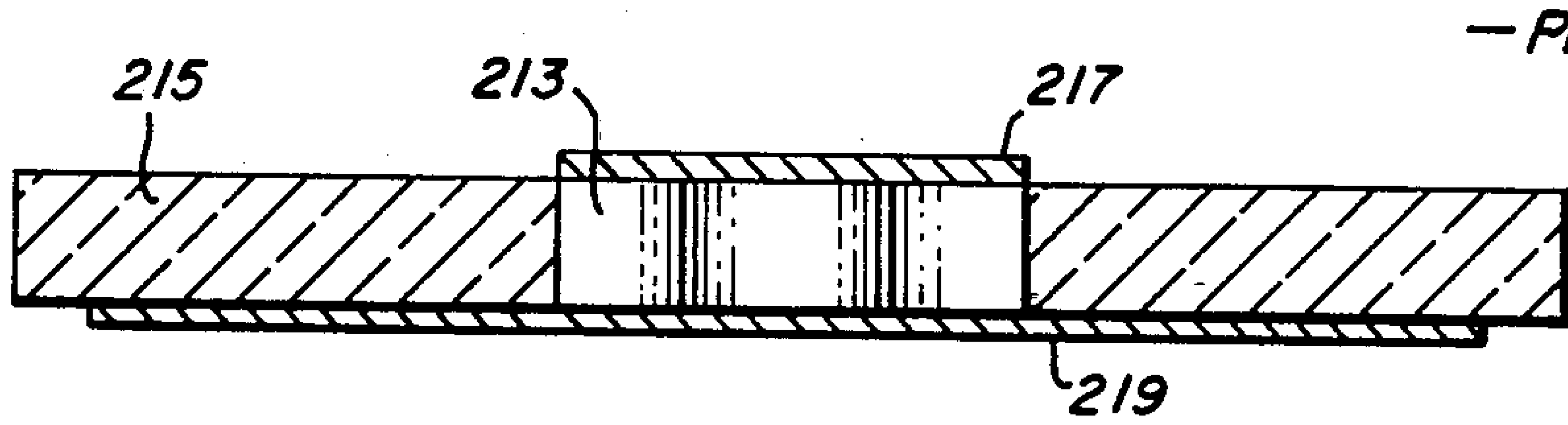


FIG.2A

—PRIOR ART—

FIG.2B

—PRIOR ART—



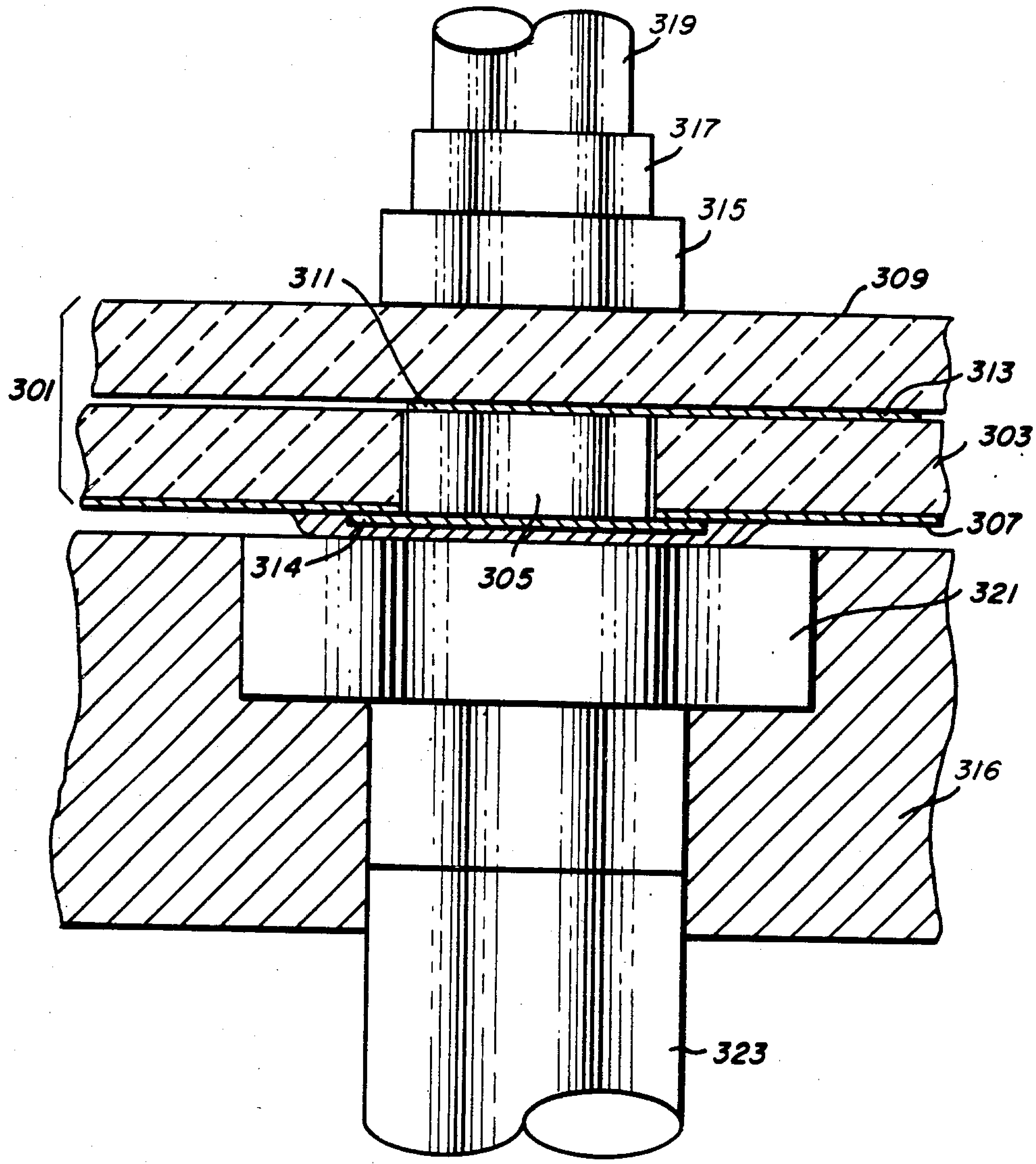


FIG. 3A

FIG. 3B

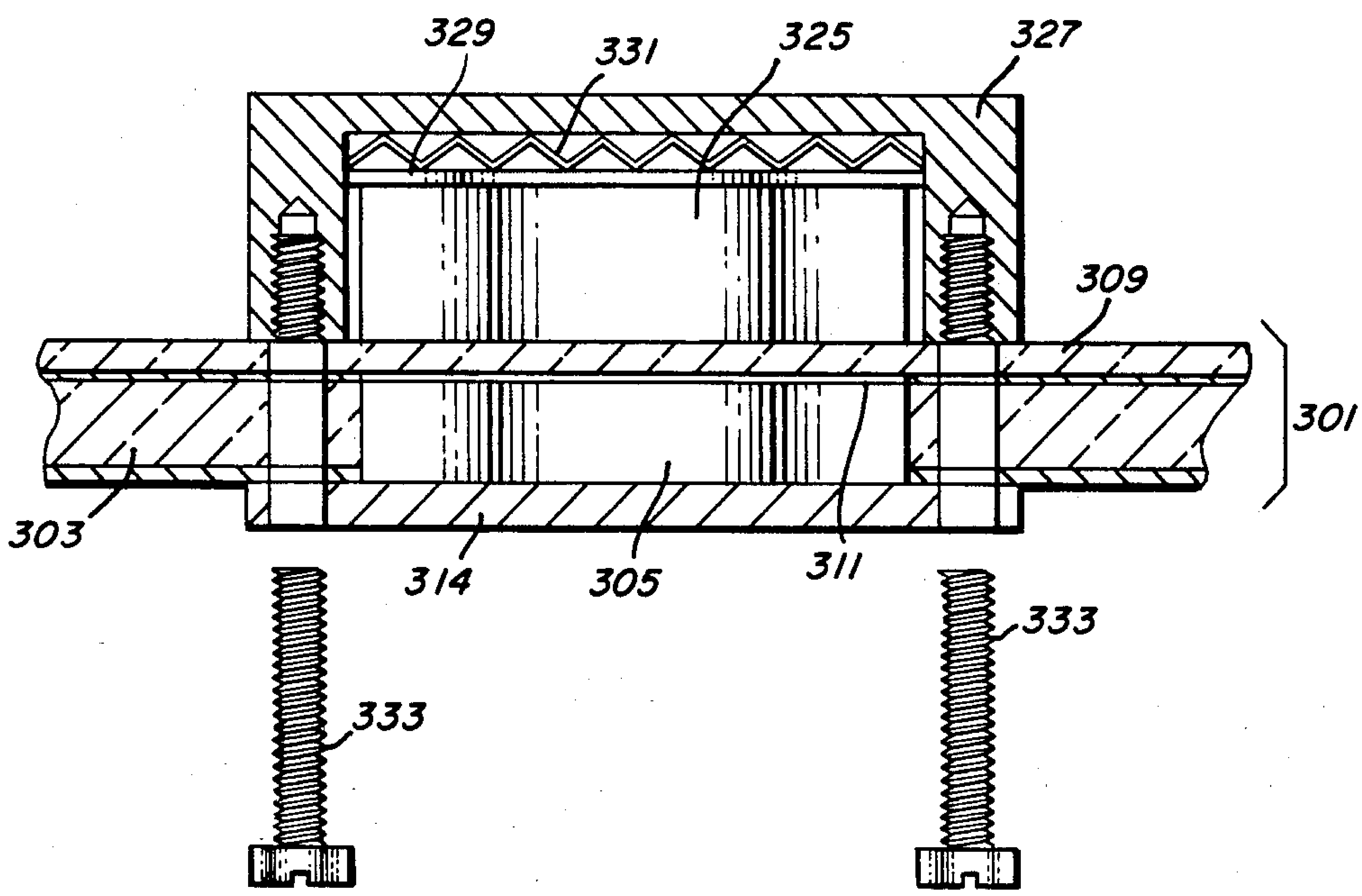
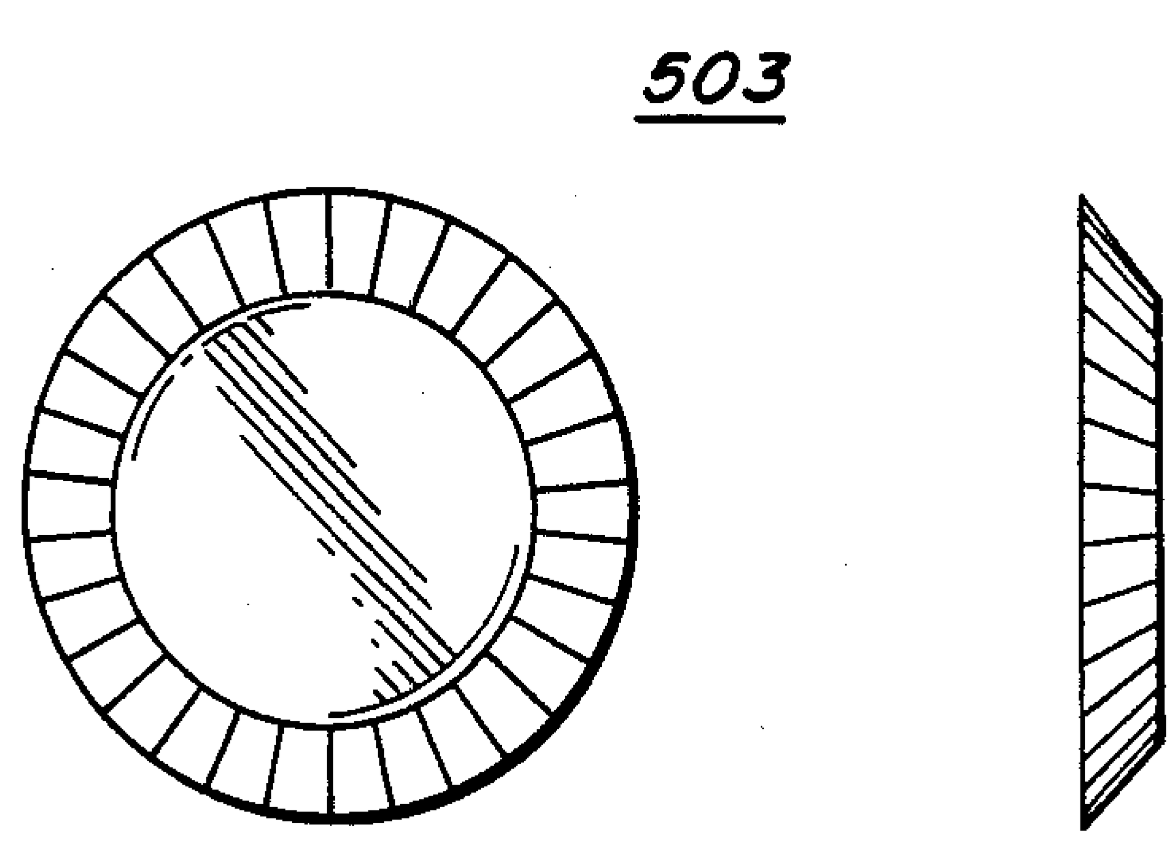


FIG. 6



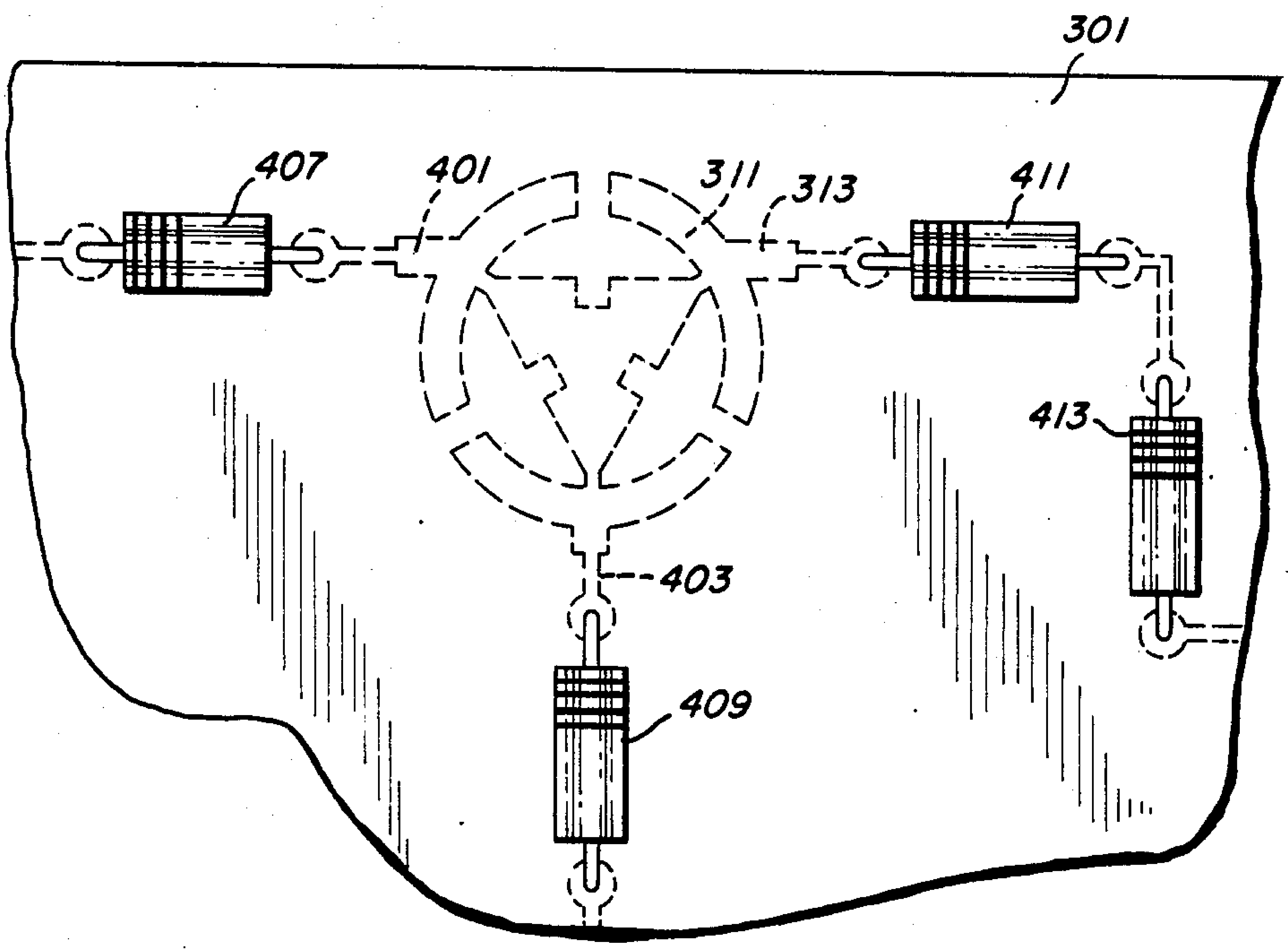


FIG. 4A

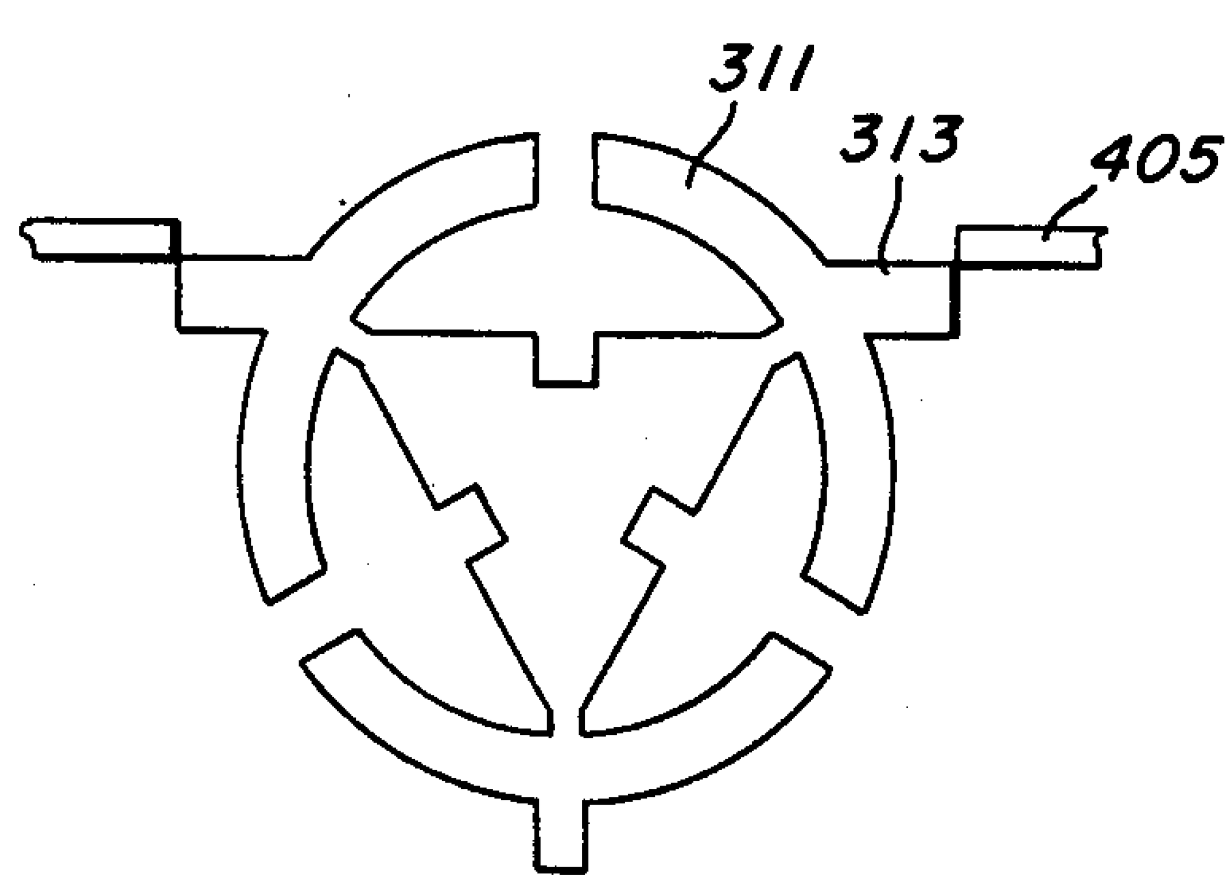


FIG. 4B

FIG. 5

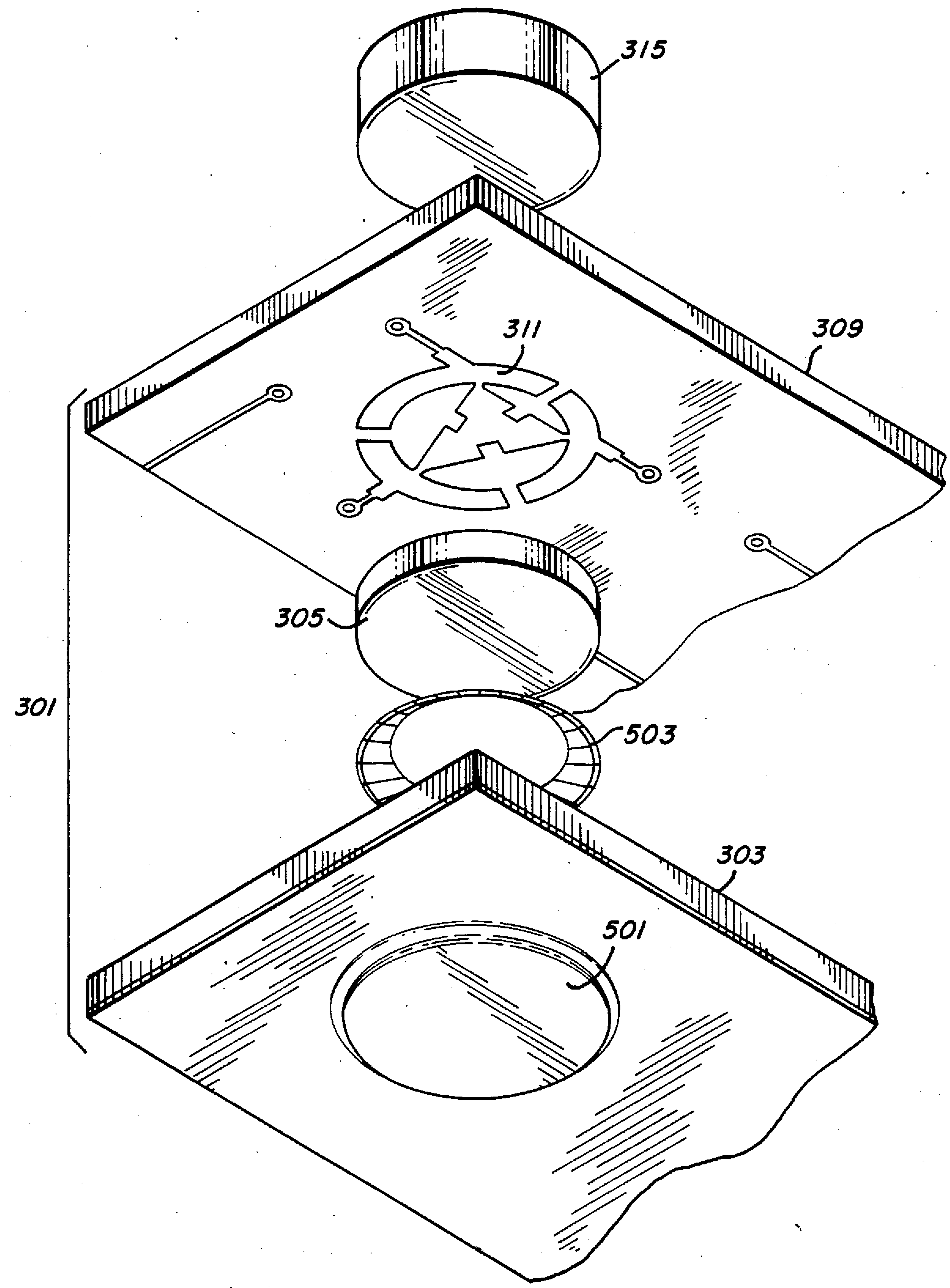


FIG. 7A

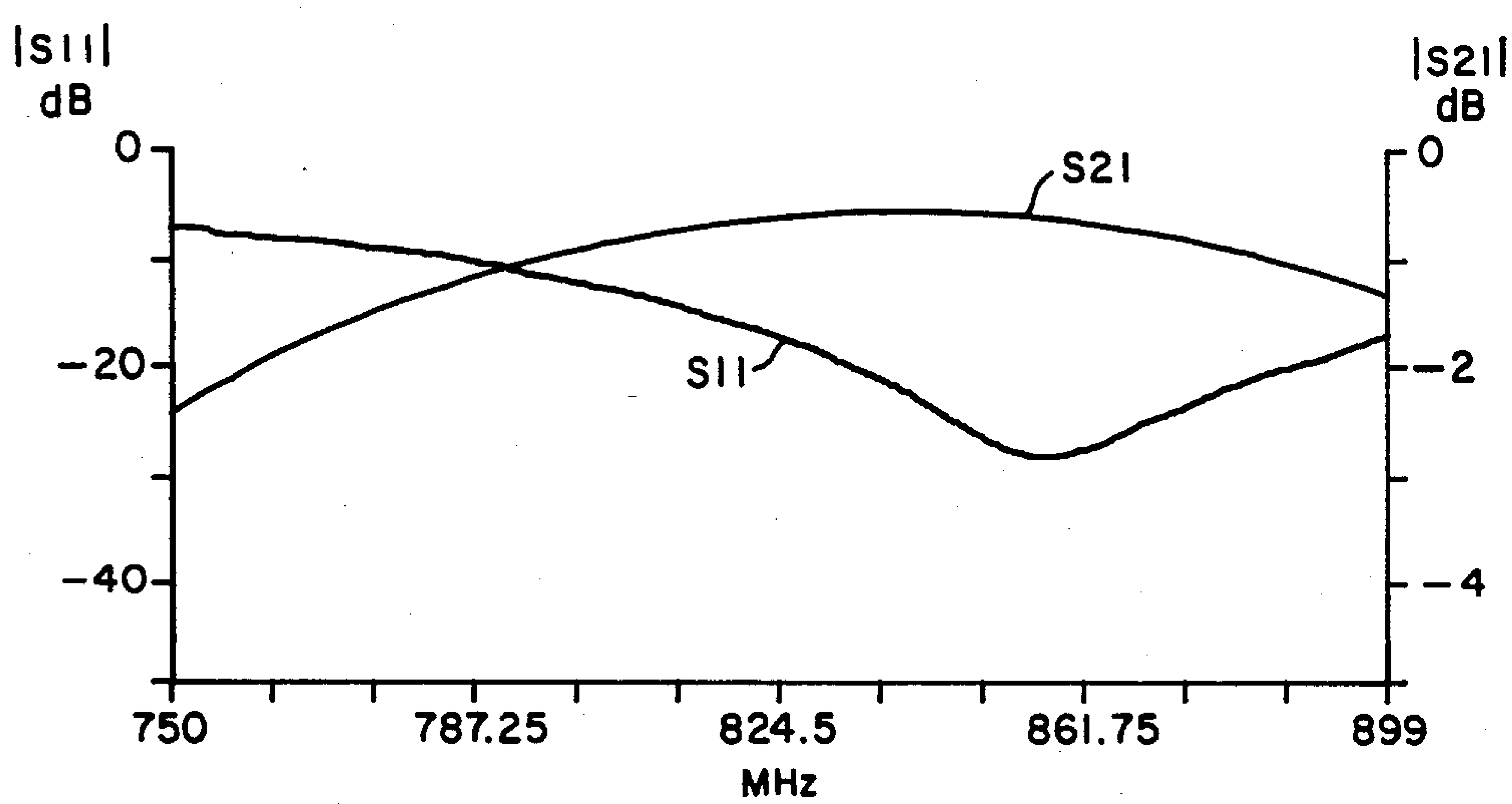
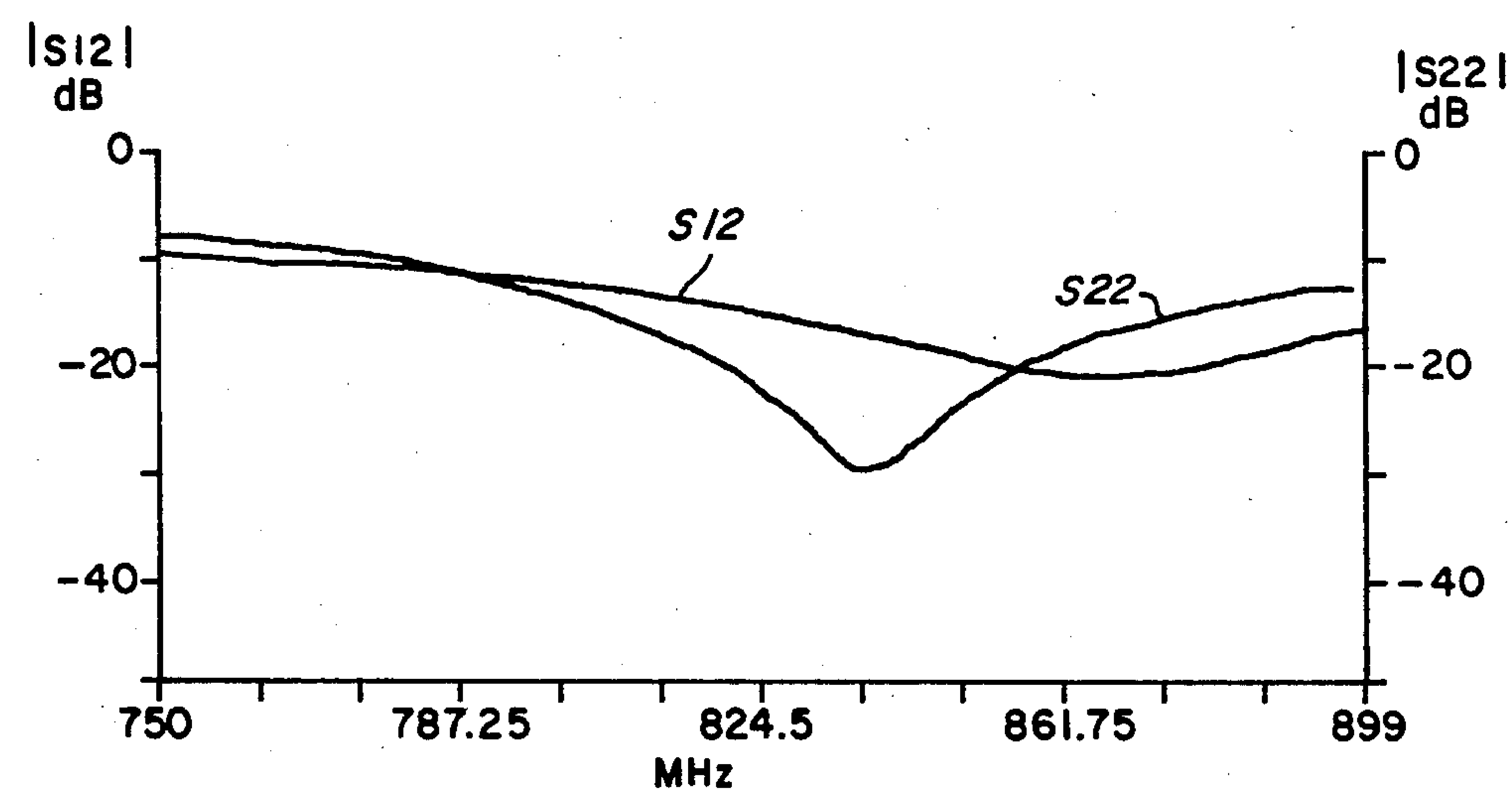

|S11| dB
|S21| dB
0
-20
-40
0
-2
-4
S21
S11
750
787.25
824.5
861.75
899
MHz

FIG. 7B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|S22| dB
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S22
750
787.25
824.5
861.75
899
MHz

MICROSTRIP CIRCULATOR WITH FERRITE AND RESONATOR IN PRINTED CIRCUIT LAMINATE

BACKGROUND OF THE INVENTION

This invention relates generally to non-reciprocal radio frequency devices and more particularly to the construction of circulators and isolators employing printed circuit microstrip resonators and ferrite disposed in layers of a multi-layer printed circuit laminate. Reference is made to copending patent application number 880,220 "Circulator/Isolator Resonator" filed on behalf of Robert C. Kane et al. on the same date as the present invention and containing related subject matter.

Circulators and isolators are well known radio frequency devices which exhibit non-reciprocal properties. A common form of circulator is that of a three-port device which couples a radio frequency signal from a first port to a second port with virtually no attenuation of the signal but which significantly attenuates a signal coupled from the second port to the first port. The signal applied at the second port is coupled to a third port. Likewise, a signal applied at the third port is coupled to the first port but greatly attenuated at the second port. Thus, the effect of the circulator is to isolate the ports from each other in one direction (ie. ports **1-3-2-1**) and to couple the ports sequentially to each other in the other direction (ports **1-2-3-1**).

Physical construction of circulators can be realized in resonant structures such as radio frequency resonant cavities and in waveguide at higher frequencies. Circulators may also be realized in planar configuration using stripline or microstrip technology which employ a planar resonating element between two ground plane conductors (stripline) or coupled to a single ground plane conductor (microstrip).

A microstrip circulator is typically constructed of an essentially planar resonating element having regularly spaced ports coupled to the periphery of the resonating element (resonator). The resonator is closely coupled to one or more elements exhibiting gyromagnetic properties (typically a ferrite material) and a magnetic field is applied perpendicular to the resonator and through the ferrite. When a radio frequency signal is applied at one port, the ferrite atoms, which have their magnetic spin vectors preferentially aligned along the magnetic lines, precess in one rotational direction. This precession favors coupling of the radio frequency signal from the port of application to the next port in the direction of the spin precession.

The preferential coupling of radio frequency signal from one port to another may be employed in a more particular application of a circulator known as an isolator. An isolator has one of the ports terminated in a resistance which matches the characteristic impedance of the circulator. This device permits radio frequency signal to propagate in one direction but blocks the propagation in the opposite direction (because the radio frequency signal energy is dissipated in the terminating resistance). This device also presents a relatively constant impedance to both the input and the output ports. Consequently, isolators are used extensively in radio transmitters and receivers where the impedance presented to an amplifying stage must be maintained close to the input or output impedance of the stage or where reflected energy could produce undesired effects or damage.

The quality of circulators and isolators is generally measured by the insertion loss in the direction of signal coupling, the amount of attenuation in the opposite direction, the impedance of each port, and the band of frequencies over which these characteristics are maintained. Optimization of these characteristics is the goal of circulator designers and has resulted in increasingly complex and expensive techniques of aligning the resonator, the ferrite, and the magnet. Additionally, improvements in cost and complexity of circulators has been realized by employing microstrip technologies rather than stripline technologies. Since microstrips require only a single groundplane and a majority of the propagating electromagnetic field is contained between the single conductor and the groundplane, only one ferrite and associated hardware is necessary to non-reciprocally transfer an applied radio frequency signal from one port of the circulator to another. Practical realizations of microstrip circulators, however, have produced circulators which require more volume than comparable stripline circulators.

SUMMARY OF THE INVENTION

Therefore, it is one object of the present invention to simply and easily enable the alignment of the resonator, the ferrite, and the magnet of a circulator or isolator.

It is a further object of the present invention to reduce the impedance mismatch at the ports of the circulator or isolator.

Accordingly, these and other objects are achieved in the present invention which encompasses the method and apparatus which reduce the input/output port termination mismatch of a microstrip circulator. The present invention employs a multilaminate dielectric circuit board disposed between opposite poles of a magnet. The multilaminate circuit board has the circulator resonator and associated input/output port leads metalized on one layer of the multilaminate circuit board and the ferrite element disposed in another layer of the multilaminate circuit board. The circuit board is arranged such that the two layers are in contact with each other and the ferrite is aligned substantially opposite the resonator.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded perspective view of conventional stripline circulator construction.

FIG. **2A** is an exploded perspective view of a conventional microstrip circulator.

FIG. **2B** is a cross sectional view of a conventional microstrip circulator in which the ferrite is placed in the substrate.

FIG. **3A** is a cross sectional view of one preferred embodiment of a microstrip circulator employing the present invention.

FIG. **3B** is a cross sectional view of a preferred embodiment of the present invention employing a single permanent magnet for biasing.

FIG. **4A** is a top view of the printed circuit board illustrating the resonator of the present invention coupled to external components.

FIG. **4B** is a bottom view of the resonator showing the port leads misaligned, a condition which the present invention alleviates.

FIG. **5** is a bottom exploded perspective view of the circulator of the present invention showing two laminations of the circuit board and the relative locations of the resonator and ferrite.

FIG. 6 is a diagram of a shim which may be employed in the present invention.

FIGS. 7A and 7B are graphs plotting the magnitude of the scattering parameters of an isolator employing the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A circulator employing conventional stripline construction is shown in FIG. 1. This construction typically employs conductive resonator **103** coupled to external circuitry via input/output port leads **105**, **107**, and **109**. Gyromagnetic material forms the dielectric between the resonator **103** and ground planes above (**111**) and below (**117**) the resonator **103**, and is usually several pieces of ferrite, shown here as ferrites **115** and **113**. The sandwich of ferrites **115** and **113** and resonator **103** along with ground planes **111** and **117** are secured between opposite poles of a biasing magnet shown as magnets **119** and **121**. Depending upon particular requirements of the circulator, a high permeability spacer (not shown) may be used to focus or spread the magnetic field. Additionally, a high permeability housing is typically used to contain the sub-components of the device and direct the field of the biasing magnet.

A conventional microstrip circulator is shown in FIG. 2A. In this implementation, a resonator **201** and input/output port leads **203**, **205**, and **207** may be realized as a discrete sub-component. Other implementations may have the resonator **201** metalized on a substrate, metalized directly upon the ferrite material **211**, or utilize a precision fit between ferrite **213** and substrate **215** as shown in cross section in FIG. 2B. (The resonator **217** is metalized over the fitted ferrite **213** on one face of the substrate and a ground plane **219** is metalized over the interface between ferrite **213** and substrate **215** on the opposite substrate face). Considering again the circulator of FIG. 2A, the microstrip ground plane **221** is typically metalized on the ferrite **211** opposite the resonator **201**. One or more magnets, shown as **223**, provide magnetic bias for the ferrite **211** and may be separated from the resonator **201** by a non-magnetic spacer **225**.

A cross-section of the circulator of the present invention in an embodiment employing a rigid mounting surface and an electromagnet is shown in FIG. 3A. (Construction of an isolator could be identical although one of the circulator ports would be terminated in a resistance equal to the characteristic impedance of the circulator). In order that the circulator of the present invention simplify alignment of the various components during construction and maintain optimum match between the output ports of the circulator and external circuit components, a multilayer printed circuit board **301** is employed. One of the laminations **303** (or layers) of printed circuit board **301** is fabricated with a hole from one side of the lamination **303** to the other such that a ferrite **305** may be emplaced at least partly in this area. In the present invention, the class of fit between the ferrite **305** and the lamination **303** is not critical. It is desirable that the ferrite **305** be easily inserted and removed from the hole; consequently, the preferred embodiment uses a clearance of at least .**001** inch between ferrite and substrate. This loose fit could not be tolerated in earlier designs employing ferrite embedded in a substrate. Additionally, one side of the lamination **303** may be metalized to provide a ground plane **307**.

A second lamination **309** of the printed circuit board **301** is metalized with the circulator resonator **311** and its port leads **313**. Lamination **309** is held in contact with lamination **303** by conventional bonding techniques used for multi-laminate printed circuit board fabrication in the preferred embodiment and the resonator **311** is held into close contact with ferrite **305** by securing a conducting bottom plate **314** to the ground plane **307** by solder, by compression of the circulator assembly with the magnet pole pieces **319** and **323**, or other means.

In order to reduce the losses through the capacitance formed by resonator **311** and pole piece **319**, a dielectric insulating spacer **315** may be interposed between pole piece **319** and the printed circuit board assembly **301**. A steel insert **321** aids in the completion of the magnetic circuit to the pole piece **323**. The entire assembly may then be secured to an aluminum chassis **316** for mechanical stability. A spacer **317** may be used to further aid in distributing the magnetic field.

The embodiment illustrated in FIG. 3A is particularly useful when pole pieces **319** and **323** are parts of an electromagnet. Pole pieces **319** and **323** may alternatively be realized as permanent magnets. The use of permanent magnets for bias enables a further simplification in the design of a circulator employing the present invention.

The cross sectional diagram of FIG. 3B shows an embodiment of the present invention employing a permanent magnet **325**. A high permeability housing **327** and conducting plate **314** are secured to the multilaminate printed circuit board **301** and each other to provide mechanical stability to the circulator. Copper and cold rolled steel (CRS) shims **329** are employed to tune and distribute the magnetic bias field. A CRS spring **331** is used to hold the entire assembly in compression when housing **327** is assembled using high permeability fasteners **333**.

Referring now to FIG. 4A, a section of laminated printed circuit board **301** is shown in top view. One of the features of the present invention is that the port leads **313**, **401**, and **403** of the circulator resonator **311** may be arranged such that impedance mismatch is minimized. Since the port leads and the resonator **311** are formed as part of the metalization of the entire circuit board, there is no mismatch due to improper port lead placement as indicated in FIG. 4B. FIG. 4B illustrates potential misalignment of port lead **313** and external circuit connection **405** which is possible for a non-integral resonator **311**, i.e. not metalized as part of the external circuit. Other translational and rotational misalignments were also possible before the solution provided by the present invention. Further, as shown in FIG. 4A, associated circuitry shown as external components **407**, **409**, **411**, and **413**, for example, may be added to the topside of printed circuit board **301** thereby incorporating the circulator resonator **311** directly into the associated circuitry without the need for terminating connectors or tabs. Thus, an entire electronic assembly including a circulator may be fabricated on a single multilaminate printed circuit board with components on one side of a layer, a metalized resonator as part of the printed circuit wiring on a second side of a layer, and in physical contact with a ferrite located in a second layer of the printed circuit board **301**.

A bottom exploded perspective view of the circulator of the present invention is shown in FIG. 5. Here, it can be seen that the ferrite **305** is carried in lamination **303** and in physical contact with the resonator **311** metalized on layer **309** of the printed circuit board **301**. Locating ferrite **305** in a hole in lamination **303** permits effective coupling of energy between the ports of the circulator. In the preferred embodiment of the present invention, a permeable metal backer **501** is added to the bottom ground plane of layer **303** to support the ferrite **305** and provide the necessary ground plane for the microstrip circulator resonator **311**. Additionally, a copper plated CRS shim stock **503** shown in FIG. **6** may be disposed between the ferrite and metal backer **501**. Shim stock **503** is a circular piece with a serrated dished edge formed to maintain positive electrical contact with the ground plane. When placed in compression, the serrated edge is forced outward against the walls of the hole in layer **303**. In one implementation of the preferred embodiment, the walls of the hole are metallized with ground plane thereby providing a conductive surface for the grounding of shim **503**.

Performance of a circulator constructed in accordance with the present invention is shown in the scattering parameter graphs of 7A and 7B. When tuned for an operating center frequency of 835.6 MHz, and employing a 0.580 inch resonator diameter on a 0.015 inch thick printed circuit board with a dielectric constant of 4.8. The ferrite was 0.656 inches in diameter, 0.030 inches thick, having a dielectric constant of 15. When a magnetic biasing field of 1600 Gauss was applied, an insertion loss (S_{21}) equal or less than −0.5 db was achieved over the band of 812 MHz to 851 MHz. Additionally, a reverse isolation (S_{12}) exceeded −18 dB over the same frequency range.

In summary then, a physically small circulator operating in the 800 MHZ to 900 MHZ frequency band has been realized in microstrip technology. Because of its small size this circulator may be constructed using a multilayer laminate printed circuit board. Such construction enables the port leads of the circulator resonator to be formed as part of the metalization of the printed circuit board and termination mismatch due to misalignment of the port leads with external circuitry is eliminated. Placement of a hole in a printed circuit board lamination directly opposite the resonator of the circulator enables a ferrite to be simply placed in proper alignment with the resonator to enable effective coupling of radio frequency energy between the ports of the circulator. Therefore, while a particular embodiment of the invention has been shown and described, it should be understood that the invention is not limited thereto since modifications unrelated to the true spirit and scope of the invention may be made by those skilled in the art. It is therefore contemplated to cover the present invention and any and all such modifications in the following claims.

I claim:

1. A method of reducing the input/output port termination mismatch of a microstrip circulator employing a dielectric circuit board having at least two layers and disposed in a biasing magnetic field, comprising the steps of:

metalizing a circulator resonator and associated input/output port leads on a first side of a first layer of the circuit board; and

emplacing a ferrite element at least partially in a second layer of the circuit board and securing a first side of said second layer to said first side of said first layer with said ferrite element substantially opposite said circulator resonator.

2. A method in accordance with the method of claim **1** further comprising the step of disposing an electrical ground plane for said circulator resonator on said second layer of said second side.

3. A method in accordance with the method of claim **2** further comprising the step of grounding said ferrite element to said electrical ground plane.

4. A method in accordance with the method of claim **1** further comprising the step of modifying the biasing magnetic field with a metal shim.

5. A microstrip circulator having reduced input/output port termination mismatch comprising:

a dielectric circuit board disposed in a biasing magnetic field and having at least first and second layers, each said layer having first and second sides;

a circulator resonator and associated input/output port leads metallized on said first side of said first layer; and

a ferrite element disposed at least partially in a second layer of said circuit board, and a first side of said second layer contacting said first layer first side with said ferrite element substantially opposite said circulator resonator metalization.

6. A microstrip circulator in accordance with claim **5** wherein said circuit board further comprises an electrical ground plane for said circulator resonator disposed on said second side of said second layer.

7. A microstrip circulator in accordance with cliam **6** further comprising a conducting shim disposed between said ferrite element and said electrical ground plane.

8. A microstrip circulator in accordance with claim **5** wherein said circulator further comprises at least one metal spacer whereby said magnetic field may be modified.

9. A microstrip circulator in accordance with claim **5** wherein said biasing magnetic field is produced by a permanent magnet.

10. A microstrip circulator in accordance with claim **9** wherein said circulator further comprises at least one dielectric spacer disposed between said permanent magnet and said first layer of said circuit board.

11. A circuit board microstrip circulator assembly having reduced input/output port termination mismatch comprising:

a dielectric circuit board having at least first and second layers, each layer having first and second sides;

a circulator resonator and associated input/output port leads metallized on said first side of said first layer;

utilization means disposed on said second side of said dielectric circuit board first layer and connected to said input/output port leads; and

a magnetically biased ferrite element disposed at least partially in a second layer of said circuit board, and a first side of said second layer contacting said first layer first side with said ferrite element substantially opposite said circulator resonator metalization.

12. A circuit board microstrip circulator assembly in accordance with claim **11** further comprising an electrical ground plane for said circulator resonator disposed on said second side of said second layer.

13. A circuit board microstrip circulator assembly in accordance with claim **12** further comprising a conducting shim disposed between said ferrite element and said electrical ground plane.

14. A circuit board microstrip circulator assembly in accordance with claim **11** wherein said magnetically biased ferrite element is magnetically biased by a permanent magnet.

15. A circuit board microstrip circulator assembly in accordance with claim **14** wherein said permanent magnet further comprises at least one metal shim.

16. A circuit board microstrip circulator assembly in accordance with claim **14** wherein said circulator further comprises at least one dielectric spacer disposed between said permanent magnet and said first layer of said circuit board.

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